NASA Technical Memorandum 103182

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Prepared for the
1990 Asia-Pacific Microwave Conference
sponsored by the Institute of Electronics, Information
and Communications Engineers
Tokyo, Japan, September 18-21, 1990

ANALYSIS OF MICROSTRIP LINES WITH ALTERNATIVE IMPLEMENTATIONS OF CONDUCTORS AND SUPERCONDUCTORS

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Abstract

This paper presents analysis of microstrip line structures in which either the strip or the ground plane or both are made of a high Tc superconductor. The effect of implementation of a superconductor to the strip and the ground plane is explained with the calculation of a conductor loss of the structure by the Phenomenological Loss Equivalence Method(PEM). The theoretical values are compared with the experimental results from a ring resonator which is made of a gold ground plane and a high Tc superconductor, $YBa_2Cu_3O_{7-x}$, strip.

Introduction

In this paper, we calculate and compare Q values of the microstrip line structures in which either the strip or the ground plane or both are a high T_c superconductor. The motivation for this study is to provide the theoretical basis for the effective application of a superconductor to the microstrip line as well as other planar transmission lines. The analytical method in this paper is based on the Phenomenological Loss Equivalence Method (PEM) [1,2] and the introduction of the superposition principle of the internal impedances from the strip and the ground plane of the microstrip line. By using this method, we calculate the Q value of the ring resonator which has a superconducting strip and a normal conducting ground and compare the results with the experimental data.

Analysis of Various Superconducting Microstrip Line Structure

We analyze the various superconducting microstrip line structures that have alternative implementations of a superconductor and a normal conductor into the strip or the ground plane as shown in Fig.1. There are field penetrations even inside of the superconductor. These field penetrations contribute to the internal impedance and cause the conductor loss in the microstrip line structure as shown in Fig.2. The internal impedances from strip conductor and the ground plane are seperately calculated by PEM. Then, the total internal impedance is obtained by using the superposition of internal impedances. The internal impedance of each case is obtained by considering the cases where either strip or the ground plane is perfect. When the ground plane is assumed to be perfect, the field penetration occurs only in the strip conductor. In this case, the geometric factor, say G1, of the microstrip line is obtained from the magnetic field penetration inside of the strip conductor. The equivalent strip [1,2] is obtained from G1. The internal impedance of microstrip line under the assumption of a perfect ground plane can be obtained as $Z_{i1} = G1 \cdot Z_{s1} \cdot \coth(Z_{s1} \cdot \sigma 1 \cdot A \cdot G1)$ where Z_{s1}, $\sigma 1$ and A are the surface impedance, the conductivity of the material and the cross section (w·t) of the strip, respecively. Next, we consider the case where the field penetration occurs only in the ground plane. In this case, the geometric factor, G2, is obtained from the field penetration in the ground plane. The internal impedance from the ground plane is obtained as $Z_{i2} = G2 \cdot Z_{s2} \cdot \coth(Z_{s2} \cdot \sigma 2 \cdot A \cdot G2)$ where Z_{s2} and $\sigma 2$ are surface impedance and conductivity of the ground, respectively. Then, the total internal impedance is obtained by adding Z_{i1} and Z_{i2}. We calculate the propagation constant of the microstip line structure by adding this internal impedance to the external impedance and by using the transmission line model. Since our method is based on the PEM, this can be applied to any field penetration depth compared with the conductor thickness as demonstrated in reference [1, 2].

Comparison Between Microstip Lines with Various Superconductor Implementation

The conductor losses of each microstrip line in Fig.1 are calculated by applying the method explained above. Then, we calculate Q values of each strip line by additional consideration of substrate loss [3]. This will give us insight to the effects of an application of superconductor on microstrip line. The dimensions of the structure are shown in Fig.3 (a). For the calculation, we use the measured conductivity values of the $YBa_2Cu_3O_{7-x}$ film obtained from the power transmitted through the film and a two fluid model [4]. The calculated Q values of each structure at 35 GHz are shown and compared in Fig.3. In this calculation, the value of 5.8×10^{-4} is used for loss tangent. Since the current is more concentrated on the strip, the implementation of a superconductor in the strip gives more influence on the loss as expected. The extent of an effect of the implementation of a superconductor in the microstrip line can be different for different geometric structures of the microstrip line.

Next, we compare our calculated results with the experimental results from the ring resonator structure shown in Fig.4. This ring resonator has the resonant frequency of 35.0 GHz The details of the fabrication of this structure and the measurements are presented elsewhere [5]. The strip of this ring resonator is a thin film of $YBa_2Cu_3O_{7-x}$ deposited on $LaAl_2O_3$ by a laser ablated technique. The ground plane consists of Ti / Au. A thin Ti layer is employed to make the deposition of the gold on the substrate and its effect on the structure is negligible because it is thin compared with a gold layer. Fig.5 shows the experimental Q values and the calculated Q values with the variation of loss tangent of the substrate. The calculated values of Q are higher than the experimental results. There are several factors for this discrepancy between the experimental and theoretical results. The ring resonator was built with a $YBa_2Cu_3O_{7-x}$ film different from the film on which the conductivity values were measured. The $YBa_2Cu_3O_{7-x}$ film used in the ring resonaltor has lower Tc and lower quality than the one used in the conductivity measurement. Also, it is more affected by the surface roughness because it is patterned. Another factor can be the edge current effect on the superconducting ring resonator. Also, since the conductor loss from the gold and superconductor decreases at the low temperature region, the substrate loss becomes more dominent. However, the information on the loss tangent of the substrate is not available at low temperature region. As we can observe in Fig.5, the Q values depend on the value of loss tangent of the substrate used in the calculation. The accurate characteristics of the substrate should be done in order to make it meaningful to compare the theoretical and experimental results.

Conclusion

In this paper, we presented a theoretical analysis of the superconducting microstrip lines with the various implementations of a superconductor and a normal conductor into the strip or the ground plane of the microstrip line. By using the method presented, we calculated the Q values of a ring resonator with the thin $YBa_2Cu_3O_{7-x}$ strip and the gold ground plane. This theoretical results are compared and discussed with experimental results of a ring resonator with the thin $YBa_2Cu_3O_{7-x}$ strip and the gold ground plane. It was found that the substrate loss becomes very critical at the superconducting microstrip line.

Acknowledgement

The authors at the University of Texas were supported by the cooperative agreement NCC-3154 from NASA and the Texas Advanced Technology Program. The PEM method was originally developed under support by grant N00014-89-J-1006 at The University of Texas at Austin from the U.S. Office of Naval Research.

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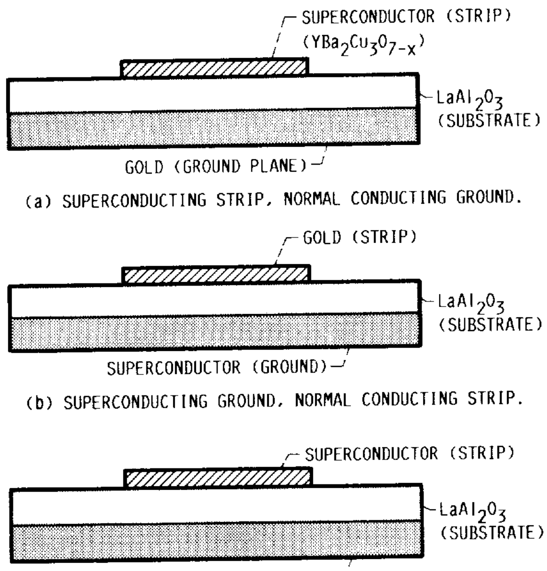


(a) SUPERCONDUCTING STRIP, NORMAL CONDUCTING GROUND.

(b) SUPERCONDUCTING GROUND, NORMAL CONDUCTING STRIP.

(c) SUPERCONDUCTING STRIP, SUPERCONDUCTING GROUND.

FIGURE 1. - SUPERCONDUCTING MICROSTRIP LINES.

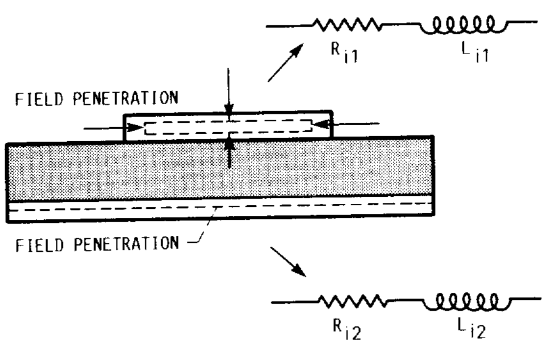
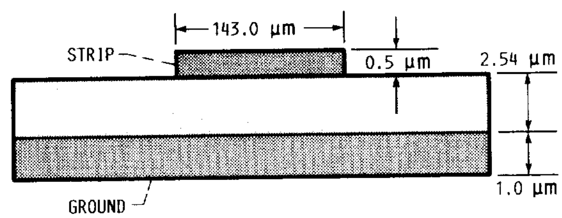
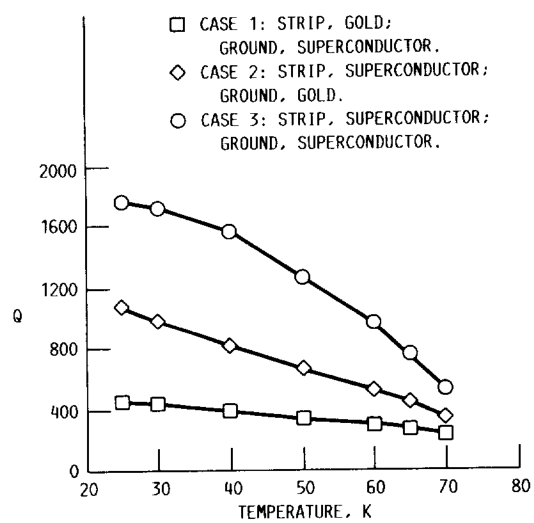


FIGURE 2. - FIELD PENETRATION IN THE STRIP AND THE GROUND PLANE.

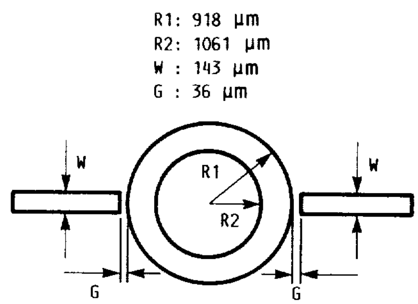


(a) MICROSTRIP LINE.

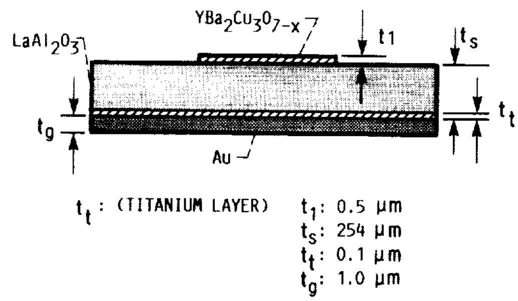


(b) Q-VALUES OF SUPERCONDUCTING MICROSTRIP LINES.

FIGURE 3. - DIMENSIONS AND Q-VALUES OF SUPERCONDUCTING STRIP LINES.



(a) TOP VIEW OF THE RING RESONATOR.



(b) SIDE VIEW OF THE RING RESONATOR.

FIGURE 4. - SUPERCONDUCTING RING RESONATOR.

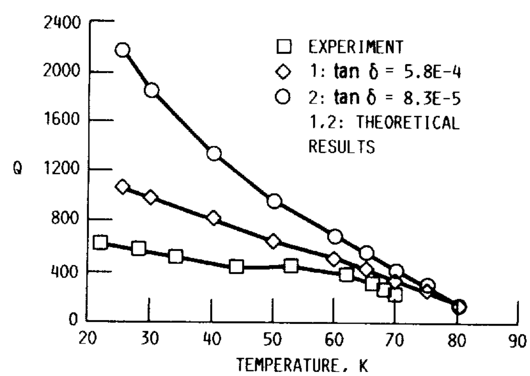


FIGURE 5. - EXPERIMENTAL AND THEORETICAL VALUES OF Q IN SUPERCONDUCTING RING RESONATOR.

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Report Documentation Page

1. Report No. NASA TM-103182	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Analysis of Microstrip Lines With Alternative Implementations of Conductors and Superconductors		5. Report Date
		6. Performing Organization Code
7. Author(s): K.-S. Kong, H.-Y. Lee, T. Itoh, C.M. Chorey, and K.B. Bhasin		8. Performing Organization Report No. E-5562
		10. Work Unit No. 506-44-20
9. Performing Organization Name and Address: National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio 44135-3191		11. Contract or Grant No.
		13. Type of Report and Period Covered: Technical Memorandum
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, D.C. 20546-0001		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the 1990 Asia-Pacific Microwave Conference sponsored by the Institute of Electronics, Information and Commercialization Engineers, Tokyo, Japan, September 18-21, 1990. K.-S. Kong, H.-Y. Lee, and T. Itoh, Dept. of Electrical and Computer Engineering, The University of Texas at Austin, Austin, Texas 78712. C.M. Chorey, Sverdrup Technology, Inc., Lewis Research Center Group, 2001 Aerospace Parkway, Brook Park, Ohio 44142. K.B. Bhasin, NASA Lewis Research Center.

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17. Key Words (Suggested by Author(s)): High temperature superconductors; Ring resonator; Microstrip lines	18. Distribution Statement: Unclassified – Unlimited; Subject Category 33

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	6	A02

NASA FORM 1626 OCT 86

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Title: Analysis of Microstrip Lines with Alternative Implementations of Conductors and Superconductors

Author(s): K.S. Kong, H.Y. Lee, T. Itoh, C.M. Chorey, K.B. Bhasin

Originating NASA Organization: LeRC

Performing Organization (if different): University of Texas at Austin

Contract/Grant/Interagency/Project Number(s): YOT 5971 506-44-20(RTOP)

Document Number(s): TM 103182 Document Date: ______

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